

AD AD

REPORT NO T98-17

**FLUID REPLACEMENT RECOMMENDATIONS
FOR TRAINING IN HOT WEATHER**

**U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts**

APRIL 1998



Approved for public release: distribution unlimited

DTIC QUALITY INSPECTED 2

**UNITED STATES ARMY
MEDICAL RESEARCH AND MATERIEL COMMAND**

19980429 070

The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or as reflecting the views of the Army or the Department of Defense.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRMC Regulation 70-25 on the use of volunteers in research.

Citations of commercial organizations and trade names in this report do not constitute an official Department of the Army endorsement or approval of the products or services of these organizations.

DTIC AVAILABILITY NOTICE

Qualified requesters may obtain copies of this report from Commander, Defense Technical Information Center (DTIC) (formerly DDC), Cameron Station, Alexandria, Virginia 22314.

DISPOSITION INSTRUCTIONS

Destroy this report when no longer needed.
Do not return to the originator.

USARIEM TECHNICAL REPORT

T98-17

FLUID REPLACEMENT RECOMMENDATIONS FOR TRAINING IN HOT WEATHER

CPT William A. Latzka, Sc.D.,
CPT Scott J. Montain, Ph.D.,
Michael N. Sawka, Ph.D.,

Thermal & Mountain Medicine Division

April 1998

U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE April 1998		3. REPORT TYPE AND DATES COVERED August 1997- April 1998
4. TITLE AND SUBTITLE FLUID REPLACEMENT RECOMMENDATIONS FOR TRAINING IN HOT WEATHER			5. FUNDING NUMBERS	
6. AUTHOR(S) William A. Latzka, Scott J. Montain and Michael N. Sawka				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Thermal & Mountain Medicine Division U.S. Army Research Institute of Environmental Medicine Bldg 42 Natick, Massachusetts 01760-5007			8. PERFORMING ORGANIZATION REPORT NUMBER T98-17	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Same as block #7			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release - distribution unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) Current U.S. Army fluid replacement guidelines emphasize fluid replacement during hot weather training to prevent degradation of performance and minimize the risk of heat injury. Little consideration has been given to possible over hydration and development of water intoxication. Sufficient epidemiological evidence is available to demonstrate that there is an increasing incidence of water intoxication during military training. This technical report presents revised fluid replacement guidelines for use during hot weather training. It summarizes the development and validation of the fluid replacement guidelines. The end product is an easy to read table that provides the user with the appropriate hourly work time and fluid intake to support work during hot weather training. The guidelines include the range of warm weather conditions likely to be encountered during military training and cover a broad range of military activities. It is expected that the revised guidelines will sustain hydration and reduce the number of heat injuries during military training while protecting the soldier from becoming sick from over drinking.				
14. SUBJECT TERMS fluid replacement, dehydration, hyponatremia, water intoxication, exercise, hot weather, heat, training			15. NUMBER OF PAGES 29	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	

TABLE OF CONTENTS

LIST OF FIGURES	iii
LIST OF TABLES	iv
EXECUTIVE SUMMARY	1
INTRODUCTION	2
HYPOTHESIS AND SPECIFIC OBJECTIVES	5
METHODS	5
RESULTS	8
DISCUSSION	18
REFERENCES	21
APPENDIX A. FORT BENNING EPICON FINAL REPORT	22
APPENDIX B. WATER AND WORK\REST CYCLE POLICY USED AT FORT BENNING (FROM FM21-10, NOVEMBER 1988)	26
APPENDIX C. PRELIMINARY FLUID REPLACEMENT GUIDELINES PROVIDED TO MARTIN ARMY HOSPITAL, FALL 1997	27

LIST OF FIGURES

Figure 1. Rectal temperature responses during work in Heat Category I conditions .	12
Figure 2. Rectal temperature responses during work in Heat Category III conditions	13
Figure 3. Rectal temperature responses during work in Heat Category V conditions	14
Figure 4. Rectal temperature responses during moderate intensity exercise in dry climate eliciting Heat Category I, III and V conditions	15

LIST OF TABLES

Table 1. Physical characteristics of the study volunteers	6
Table 2. Work:rest cycles and water requirements for humid climate tests	7
Table 3. Work:rest cycles and water requirements for moderate work in dry climates	7
Table 4. Metabolic rates and sweating rates for men during work in the heat	9
Table 5. Metabolic rates and sweating rates for women during work in the heat	10
Table 6. Fluid Replacement Guidelines* for Warm Weather Training (Average Acclimated Soldier wearing BDU, Hot Weather)	17

EXECUTIVE SUMMARY

The U.S. Army FM 21-10 provides fluid replacement guidance for soldiers performing hot weather training. One weakness of the existing doctrine is that it doesn't consider that soldiers can become sick from drinking excessive quantities of water during training. Epidemiological evidence is accumulating that some soldiers are drinking in excess of water need during training and becoming sufficiently sick to require hospitalization. At the request of the U.S. Army Center for Health Promotion and Medicine and Ft. Benning Training Brigade we were tasked to revise the fluid replacement guidelines for hot weather training. This report summarizes our efforts to determine the appropriate fluid replacement and work:rest combinations when working in hot climates. Our initial effort used the predicted sweating rates from the USARIEM Heat Strain Model and the Scenario Model for exercise in a variety of hot weather situations to develop a table that provided guidance for fluid replacement and proper work:rest to sustain work with minimal heat casualties. These predictions were then compared to existing data, where available. A laboratory validation study was then performed to systematically verify our recommendations. For the study, soldiers performed exercise which elicited energy costs approximating low, moderate and hard military tasks in Heat Category I, III and V conditions. We found that the models adequately predicted the appropriate work:rest ratio for the work intensities but generally overestimated the actual sweating rates by approximately $\frac{1}{4}$ qt/h. The fluid replacement guidelines were revised and are presented in this technical report.

INTRODUCTION

In July 1997, Martin Community Hospital, Ft. Benning, GA, notified the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM), Aberdeen Proving Ground, MD, that 5 cases of hyponatremia had been identified in trainees over the past month, one terminating fatally. Hyponatremia is defined by low blood sodium concentrations (serum sodium < 135) and is generally caused by hypervolemia secondary to extensive over drinking. An epidemiological consultation (EPICON) was requested to assist investigation of these cases. Physiologists from the U.S. Army Research Institute of Environmental Medicine (USARIEM), Natick, MA, participated on the EPICON investigation.

It was determined that between 1989 and 1996 there had been 125 (average ~16 annually) cases of documented hypo-osmolality /hyponatremia (MSMR, 1997). Forty percent of all Army cases occurred at Fort Benning (n=50). In 1996-1997, 11 cases of hyponatremia were identified at Fort Benning and these records were reviewed. These cases were characterized as being Caucasian, occurring early in the training cycle, associated with large fluid intake, mental status changes, nausea, and vomiting. All cases occurred in heat stress. The average serum sodium was 121 mEq/L (range 116-133). Calculations indicate that total body water must be increased by 3 to 5 liters to achieve such a low serum sodium values. It seemed that the prevailing belief by unit leaders was that all heat illnesses were dehydration mediated and should be treated by aggressive rehydration regardless of symptoms (including persistent nausea and emesis). The EPICON team recommended that criteria for evaluation and evacuation of heat casualties be revised and that the existing fluid replacement guidelines (Appendix A) be modified.

In August 1997, USARIEM was tasked by CHPPM to revise the Fort Benning water replacement guidelines for hot weather training. The changes were requested to minimize problems from both dehydration and water intoxication. The existing Army fluid replacement guidelines (provided in FM 21-10, Field Hygiene and Sanitation; Appendix B) were written to prevent heat injuries and emphasize the importance of adequate hydration and prevention of dehydration - with the assumption that overdrinking would be balanced by increased urine output. The doctrine did not

differentiate water requirements for various work intensities. This omission in the doctrine may have contributed, in part, to some of the cases of over hydration.

In September 1997, USARIEM provided modifications (Appendix C) to the fluid replacement guidelines. The revised fluid replacement guidelines were constructed to include three metabolic rates that are frequently encountered for military tasks (Pandolf, Stroschein, Drolet, Gonzalez, and Sawka, 1986) and the five Heat Categories that were in the old guidance. The USARIEM Heat Strain Model (Pandolf, Stroschein, Drolet, Gonzalez, and Sawka, 1986) was used to estimate sweating rates for an average size soldier performing easy, moderate, and hard military tasks, in climates ranging from 70 to 110 °F and 20 to 100% relative humidity in full sun and in full shade conditions. Wind speed for all calculations was kept constant at 2.5 mph. The uniform was hot weather Battle Dress Uniform (BDU). The matrix was then collapsed by placing each weather condition in the appropriate Heat Category based on WBGT temperatures and the sweat rate responses were averaged by Heat Category I, II, III, IV and V and rounded to the nearest ¼ quart.

The fluid replacement table generated from the USARIEM Heat Strain Model was then compared to a second model (SCENARIO, Kraning and Gonzalez, 1997) which also estimates sweating rates during exercise in hot climates. When the latter model estimated sweating rates and temperature responses lower than the former model's predictions, the work rest cycles and water requirements were revised to accommodate the differences between the predictions. The work:rest cycles were constructed to maximize work output while minimizing the likelihood of incurring heat casualties. In all situations, the length of the work:rest cycles were estimated from the predicted core temperature responses to work in the specified Heat Category and were set to prevent core temperatures from rising above 38.5°C during 4 h of sustained training. The core temperature of 38.5°C represents two standard deviations below the mean core temperature where soldiers (healthy, euhydrated and reasonably fit) will discontinue work under worst-case heat stress conditions (Sawka, Young, Latzka, Neufer, Quigley, and Pandolf, 1992).

A potential problem with the predicted values, however, is that the models estimated core temperatures, sweating rates, and fluid requirements based on an

algorithm developed using a variety of clothing and conditions; with relatively little data from persons wearing desert or hot weather BDU. The recommendations, therefore, required validation before they could be used to determine Army fluid replacement policy. Furthermore, since the water requirements and work rest cycles were set within heat categories defined by WBGT range, it is also important to determine if the models provide appropriate estimates for sweating in both hot-dry and hot-wet climates with similar WBGT values.

HYPOTHESIS AND SPECIFIC OBJECTIVES

The purpose of this study was to validate the water requirements for soldiers working at intensities approximating easy, moderate and hard military tasks in three Hot weather conditions while wearing hot weather Battle Dress Uniforms (BDU). It was hypothesized that the sweating rates would be similar to fluid replacement estimates derived from the USARIEM Heat Strain Model and Scenario. The specific objectives of the protocol were:

1. Validate water recommendations against actual sweating rates during easy, moderate and hard exercise in Heat Categories I, III and V while wearing hot weather BDUs.
2. Evaluate water requirements between hot-dry and hot-wet conditions during moderate intensity exercise in Heat Category I, III, and V.
3. Revise water recommendations for soldiers performing easy, moderate and hard military tasks in hot weather accordingly.

METHODS

SUBJECTS

Twenty soldiers (14 men and 6 women) volunteered to participate in the study. Table 1 presents the soldiers' characteristics. One male volunteer dropped out of the study prior to beginning experimental testing and was not included in the data analysis. All were healthy, less than 40 yrs of age, with no medical history of heat intolerance or

heart disease. The protocol was approved by the appropriate institutional review boards and all volunteers were informed both verbally and in written form of the objectives and procedures of the study.

Table 1. Physical characteristics of the study volunteers.

	Age, yr	Height, cm	Weight, kg	2 mile run time, min
Men (n=13)	20±3	173±7	78.9±11.7	13.9±0.9
Women (n=6)	21±3	165±9	66.9±11	17.0±0.7

EXPERIMENTAL DESIGN

Volunteers performed a five day heat acclimation program prior to experimental tests to minimize thermal and cardiovascular adaptations associated with repeated exercise-heat stress during the experimental testing. The five day heat acclimation period was chosen because most adaptations to repeated heat stress, including increased sweat rate, occur within four days of heat exposure (Sawka, Wenger, and Pandolf, 1996). The heat acclimation protocol consisted of two 50 min exercise bouts separated by 10 min rest. Volunteers walked on a treadmill at 3.5 mph at 4% grade in a hot dry climate (46°C, 25% rh) wearing the U.S. Army Physical Training uniform. Rectal temperature and heart rate were measured throughout exercise. Volunteers were provided water ad libitum during the heat acclimation procedures.

Following the heat acclimation protocol, the volunteers performed up to 12 exercise-heat stress tests (HST) trials; walking at three exercise intensities (approximately 250 W, 425 W and 600 W) in three humid climates (Table 2), as well as the moderate exercise intensity in three dry climates (Table 3). The order of climatic conditions for the HSTs were randomized, with the exception that the dry conditions were generally tested following completion of the humid climate HSTs.

During the HSTs volunteers wore hot weather BDU with tennis shoes (to help prevent blisters). Sleeves were down, and pants bloused. All volunteers wore the warm weather BDU cap. The work/rest cycles predicted by the models were used for each weather-exercise intensity combination - with volunteers sitting on a bench during

each rest period. The total heat stress exposure was 120 min for each condition. The work periods were evenly spaced within each 120 min exercise exposure. The volunteers drank the recommended volumes of water given in Table 2 and Table 3. Metabolic rates were measured between 10 to 20 min of each work period. When no limit was placed on exercise time, a second metabolic rate measurement was collected between 70-80 min of exercise.

Table 2. Work:rest cycles and water requirements for humid climate tests.

Heat Category (WBGT) Ta (°C),rh		Easy Work (250 W)		Moderate Work (425 W)		Hard Work (600 W)	
		work/ rest (min)	water Intake (qt/h)	work/ rest (min)	water Intake (qt/h)	work/ rest (min)	water Intake (qt/h)
I (25.6°C)	28°C, 75%	NL	0.5	NL	0.75	40/20	1.0
III (29.5°C)	32°C, 75%	NL	1.0	40/20	1.0	30/30	1.25
V (33.3°C)	36°C, 75%	NL	1.25	30/30	1.25	20/40	1.25

Table 3. Work:rest cycles and water requirements for moderate work in dry climates.

Heat Category (WBGT) Ta (°C), rh		Moderate Work (425 W)	
		work/rest (min)	water Intake (qt/h)
I (25.6°C)	36°C, 25%	NL	0.75
III (29.5°C)	41°C, 25%	40/20	1.0
V (33.3°C)	46°C, 25%	30/30	1.25

The start time for all HSTs was held constant for each subject throughout the experimental protocol to control for circadian rhythms. Semi nude body weight and clothed weight were measured before and after each HST to determine whole body sweat loss; males wore Spandex shorts and females wore Spandex shorts and sports

bras under their BDU to facilitate weighing.

EXPERIMENTAL PROCEDURES

Rectal temperatures were measured with a thermistor inserted ~8-10 cm past anal sphincter. Heart rate was measured using the Polar Heart Rate Monitor. Douglas bags (2 minute collection) and indirect calorimetry were used to determine the metabolic cost of exercise between 10-20 min of each work period. Body weights were measured to the nearest ± 20 g before and after exercise. Whole body sweating rate was calculated from the change in pre to post- exercise body weight (measured semi nude) after correcting for water intake, urine production, metabolic water loss (assuming 0.12 g/kilocalorie) and respiratory water loss (0.11 g/kilocalorie).

STATISTICAL ANALYSIS

The sample size was chosen in order to obtain a normal distribution of the data. Preliminary power estimates suggested that approximately 20 people per cell would be adequate to detect a 0.2 L/ h difference in sweating at $P < 0.05$ and power =90. Descriptive statistics were used to compare the study results to the predicted values. A difference of greater than ± 1 standard deviation was considered significant, and the water replacement table modified accordingly.

RESULTS

The volunteers completed the 12 trials without medical incident. On several occasions, however, one or more volunteers were not available to test on a specific day. The data for the exercise intensity - heat category were, therefore, compared to predicted values using the smaller sample size.

The metabolic rates and measured sweating rates for each exercise-heat category combination are presented for the men in Table 4. The work rates chosen elicited the desired metabolic rates, averaging 304 ± 39 , 415 ± 42 , and 614 ± 66 watts, respectively. In general, the measured sweating rates were lower than predicted, with 7 of 9 exercise-heat category combinations averaging > 1 sd from the predicted values and 2 of 9 (Heat category III low and hard intensity trials) averaging > 2 sd less than

predicted. The magnitude of deviation varied depending on the heat category and exercise intensity, but ranged from 0.03 to 0.38 qt/h less than predicted.

Table 4. Metabolic rates and sweating rates for men during work in the heat.

Heat Category	Climate	Easy Work		Moderate Work		Hard Work	
		Metabolic Rate, watts	Sweating Rate, qt/h	Metabolic Rate, watts	Sweating Rate, qt/h	Metabolic Rate, watts	Sweating Rate, qt/h
I	Wet	296±44	0.38±0.07	414±41	0.62±0.10	611±66	0.79±0.12
	Dry			410±41	0.83±0.14		
III	Wet	308±53	0.67±0.14	430±38	0.77±0.14	610±67	0.87±0.15
	Dry			395±46	0.76±0.09		
V	Wet	307±39	1.13±0.35	421±38	1.10±0.13	622±65	1.07±0.12
	Dry			418±48	0.93±0.14		

Data are means±sd

The metabolic rates and measured sweating rates for each exercise-heat category combination are presented for the women in Table 5. Similar to the men, the work rates chosen elicited the desired metabolic rates, averaging 252±51, 420±36, and 619±55 watts, respectively. The measured sweating rates were substantially less than predicted from the models, averaging 0.27, 0.58, and 0.57 qt/h less than predicted for Heat Category I, III, and V conditions, respectively. This was not surprising, however, as the models predicted sweating rate for the average sized male soldier and the values obtained were not adjusted for differences in body size.

Rectal temperature responses to the easy, moderate and hard exercise trials are reported for Heat Category I, III, and V in Figures 1-3, respectively. During Heat Category I conditions there were no restrictions placed on work time during easy and moderate intensity work and rectal temperatures plateaued at approximately 37.4°C and 37.7°C, respectively. Hard work produced a rapid increase in rectal temperature reaching a peak of approximately 38.0°C during both work period 1 and 2. These results suggested that the work:rest ratios were adequately conservative to support soldier work for sustained periods (> 4 h).

Table 5. Metabolic rates and sweating rates for women during work in the heat

Heat Category	Climate	Easy Work		Moderate Work		Hard Work	
		Metabolic Rate, watts	Sweating Rate, qt/h	Metabolic Rate, watts	Sweating Rate, qt/h	Metabolic Rate, watts	Sweating Rate, qt/h
I	Wet	256±69	0.26±0.11	424±29	0.52±0.14	590±50	0.57±0.17
	Dry			402±43	0.71±0.13		
III	Wet	245±36	0.35±0.16	433±29	0.60±0.14	643±55	0.57±0.17*
	Dry			412±30	0.60±0.13		
V	Wet	255±47	0.68±0.31	426±43	0.72±0.35	624±59	0.81±0.23
	Dry			425±41	0.65±0.18		

Data are means±sd. *Contains the data of several volunteers that did not perform the prescribed amount of work due to achievement of 90% of age predicted heart rate.

During Heat Category III conditions, the suggested work:rest ratios for low, moderate and hard work were appropriate to prevent progressive core temperature increments during the 2 h work period. During low intensity exercise, core temperature plateaued after approximately 50 min of exercise at rectal temperature of 37.5°C, with little further rise over the final 70 min of exercise. During moderate intensity exercise, the core temperature rise accompanying 40 min of work resulted in temperatures of 37.7° and 37.8° at the end of work period 1 and 2. During hard work, the male's rectal temperatures rose to 38.0° and 38.2°C during work period 1 and work period 2, respectively, and provided sufficient safety margin below our criterion value of 38.5°C to suggest that the 30:30 work:rest ratio was appropriate for hard work in Heat Category 3 conditions.

During Heat Category V conditions, the core temperature response to work increased progressively with successive bouts of exercise and/or time. During low intensity work, the rectal temperatures steadily rose over the 2 h and the group mean reached 38.3°C after 120 min of exercise. While temperature did not exceed our 38.5°C criterion, the steady increase suggested that incorporation of a short rest period should be included. During moderate intensity exercise, the 30:30 work:rest ratio did not prevent a 0.3°C higher rectal temperature after work period 2, and core temperatures of approximately 38.2°C after 2 h of exercise-heat exposure. During hard

work, rectal temperatures rose from approximately 37°C at rest to 38°C after 15 min of work. Forty-five minutes rest did not provide adequate cooling to return core temperature below 37.7°C and the second 15 min bout increased core temperature above 38.5°C. These findings suggest that even bouts of 15 min duration still place excess thermal stress on the soldier attempting to perform hard work in Heat Category V conditions, and further reductions to work time are necessary if no modifications to clothing (unblouse pants, remove BDU top) and/or work intensity are included to sustain work in these heat category conditions.

Figure 4 presents the rectal temperature responses of the soldiers performing moderate intensity work in the desert climates eliciting Heat Category I, III and V conditions. In general, the rectal temperature response to moderate intensity exercise in the hot-wet and hot-dry climates were similar when normalized to WBGT. In Heat Category I conditions, the core temperature rose to 37.6-37.7°C with no upward drift in temperature in both the wet and dry weather conditions. In Heat Category III conditions the core temperature rose 0.1-0.2°C less in the dry climate compared to the wet climate, despite no difference in hourly sweating rate. In both wet and dry climates, the hourly work time restrictions were conservative enough to prevent upward drift in rectal temperature over the 2 h work period. In Heat Category V conditions the rectal temperature response was nearly identical between the wet and dry conditions, with a progressive increase in rectal temperature from bout 1 to bout 2 - supporting the necessity of incorporating a more conservative work time for moderate work in Heat Category V conditions.

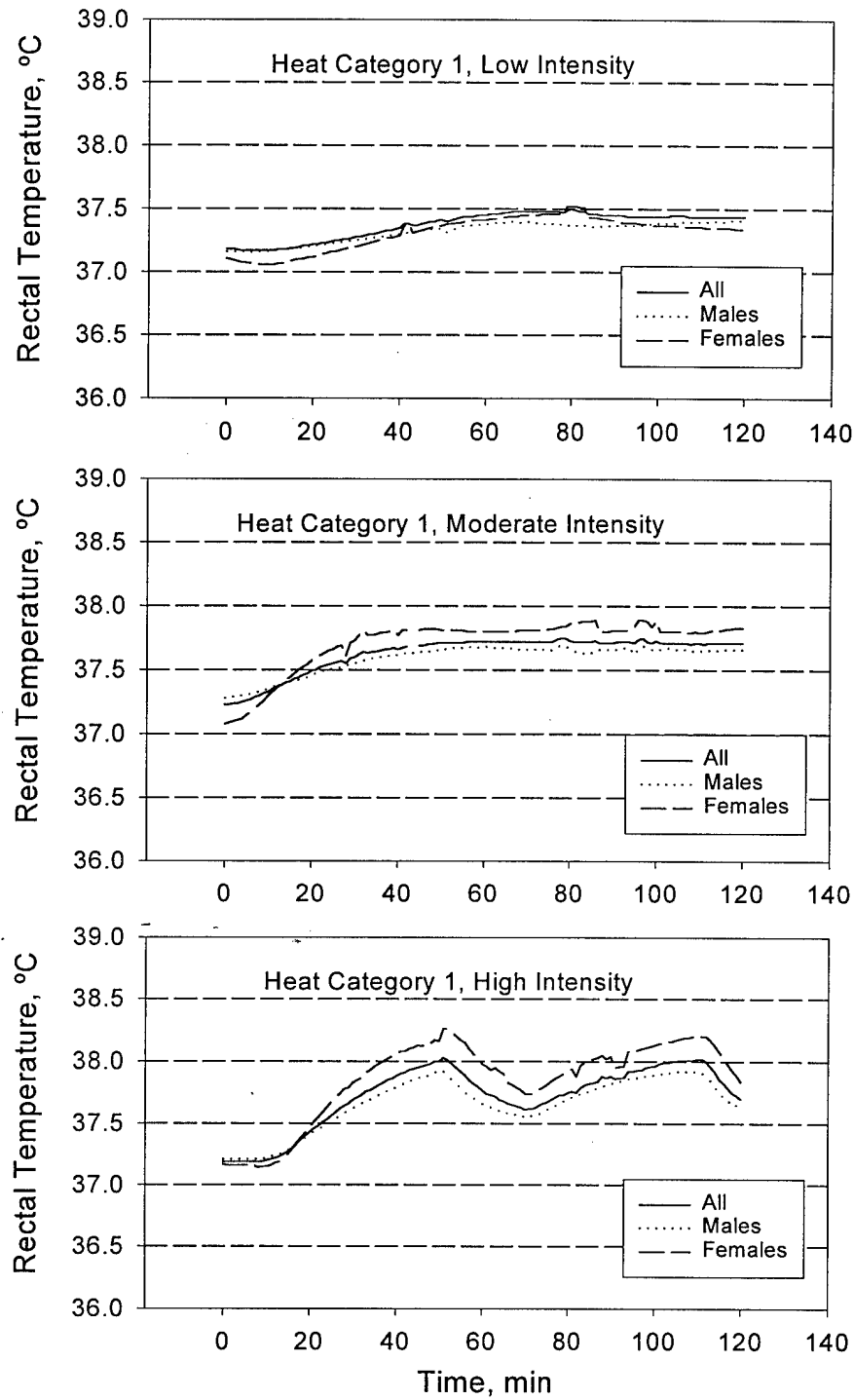


Figure 1. Rectal temperature responses during work in Heat Category I conditions.

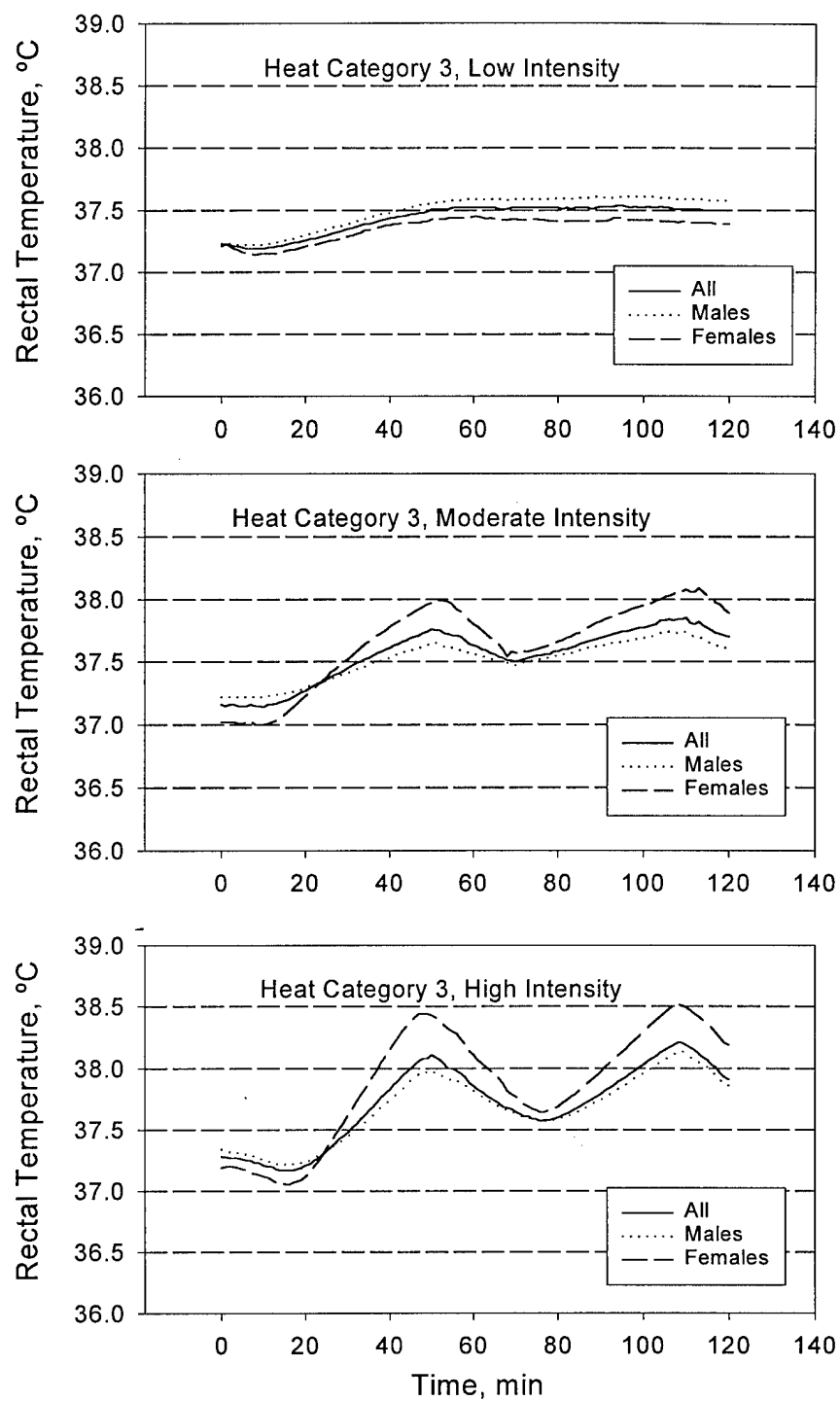


Figure 2. The rectal temperature responses during work in Heat Category III conditions.

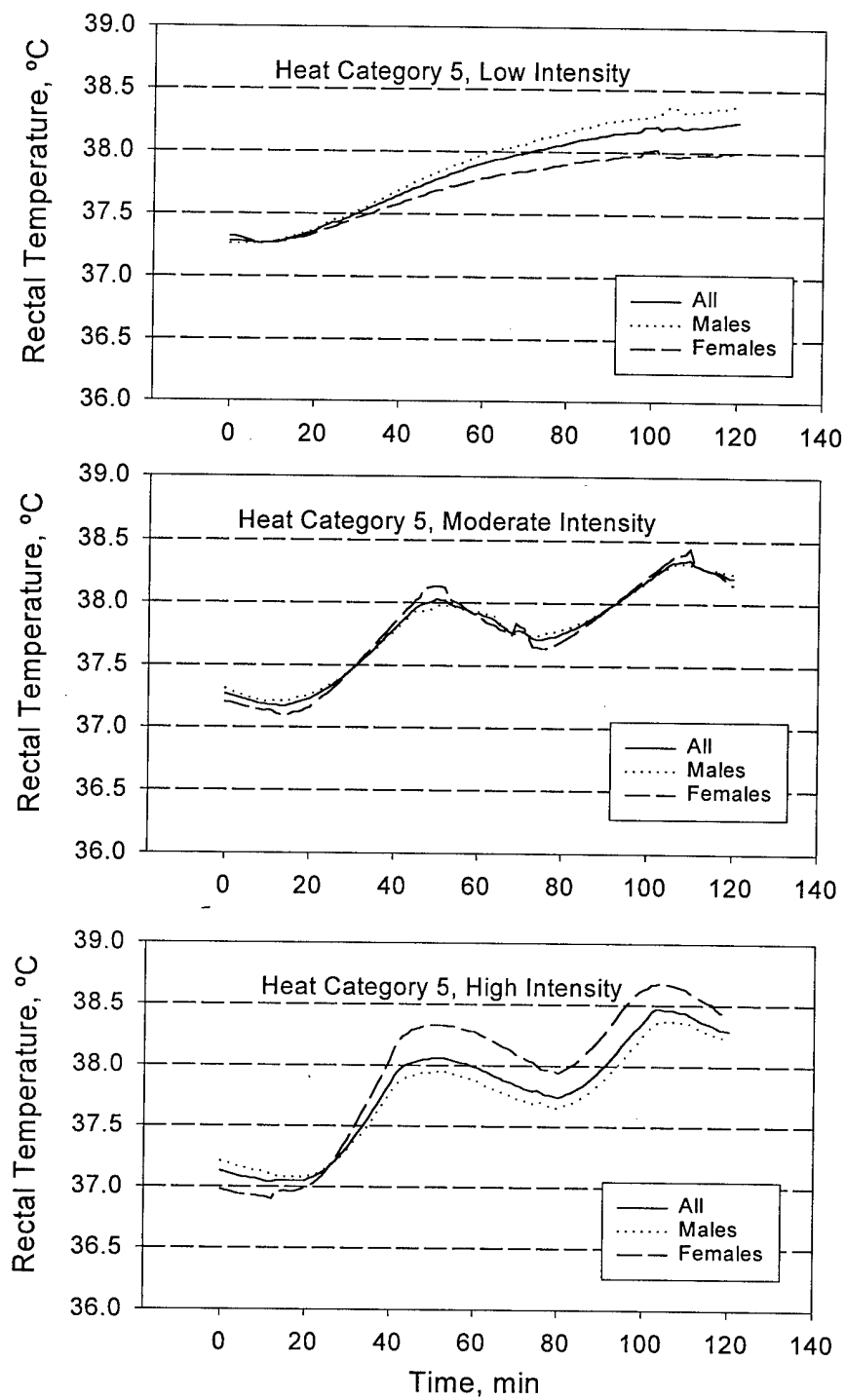


Figure 3. The rectal temperature responses during work in Heat Category V Conditions

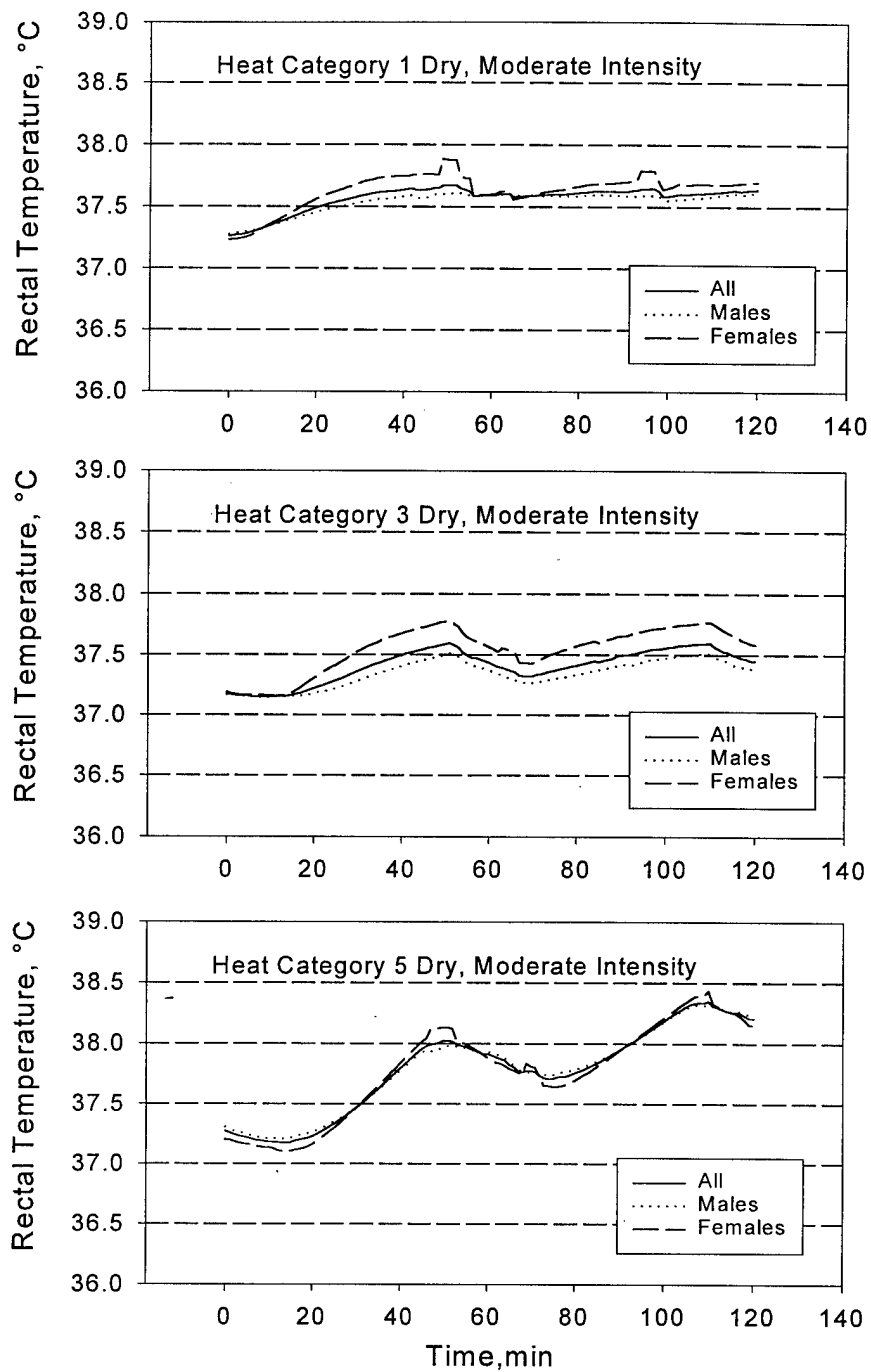


Figure 4. Rectal temperature responses during moderate intensity exercise in dry climate eliciting Heat Category I, III and V conditions. The abrupt rectal temperature increase at 49 min for females in Heat Category I was due to 2 volunteers stopping temporarily to urinate.

REVISIONS TO THE TABLE

Based on the sweating rate and rectal temperature responses to exercise in each heat category, the recommended water intake was reduced from our initial recommendation. We also added a work:rest recommendation to the easy work in Heat Category V conditions and modified the work:rest recommendation initially recommended for moderate and hard work in Heat Category V conditions. These work:rest modifications were done to reduce the likelihood of a soldier becoming a heat casualty from excessive increases in core temperature during training. The revised table is presented in Table 6.

All changes to the fluid replacement recommendations were based on the sweating rate data of the male soldiers. This was done because men make up the majority of soldiers and they generally sweat more profusely than women. It was felt that this would provide sufficient water intake to sustain hydration of most soldiers without allowing the soldiers with the highest sweating rates to become overly dehydrated over 4 h of work. Adjustments to the work:rest recommendations were made, where appropriate, to decrease the likelihood that soldiers would exceed rectal temperatures of 38.5-38.7°C during 4 h of work.

Table 6. Fluid Replacement Guidelines for Warm Weather Training (Average Acclimated Soldier wearing BDU, Hot Weather).

Heat Category	WBGT Index, °F	Easy Work		Moderate Work		Hard Work	
		Work /Rest	Water Intake, Qt/h	Work /Rest	Water Intake, Qt/h	Work /Rest	Water Intake, Qt/h
1	78-81.9	NL	½	NL	¾	40/20 min	¾
2	82-84.9	NL	½	50/10 min	¾	30/30 min	1
3	85-87.9	NL	¾	40/20 min	¾	30/30 min	1
4	88-89.9	NL	¾	30/30 min	¾	20/40 min	1
5	> 90	50/10 min	1	20/40 min	1	10/50 min	1

- The work:rest times and fluid replacement volumes will sustain performance and hydration for at least 4 h of work in the specified heat category. Individual water needs will vary \pm ¼ qt/h.
- NL= no limit to work time per hour. Rest means minimal physical activity (sitting or standing) and should be accomplished in shade if possible.
- **Caution: Hourly fluid intake should not exceed 1½ quarts.**
- **Daily fluid intake should not exceed 12 quarts.**
- MOPP gear adds 10°F to WBGT Index.
- Examples:

Easy Work	Moderate Work	Hard Work
<ul style="list-style-type: none"> • Weapon Maintenance • Walking Hard Surface at 2.5 mph, \leq 30 lb Load • Manual of Arms • Marksmanship Training • Drill and Ceremony 	<ul style="list-style-type: none"> • Walking Loose Sand at 2.5 mph, No Load • Walking Hard Surface at 3.5 mph, \leq 40 lb Load • Calisthenics • Patrolling • Individual Movement Techniques, i.e. low crawl, high crawl • Defensive Position Construction • Field Assaults 	<ul style="list-style-type: none"> • Walking Hard Surface at 3.5 mph, \geq 40 lb Load • Walking Loose Sand at 2.5 mph with Load

DISCUSSION

The objective of this project was to develop fluid replacement guidelines which provide valid guidance regarding appropriate work time and fluid intake during warm weather training. To accomplish this objective, the table needed to include recommendations based on the existing climatic conditions and the planned physical activity - as these two variables determine the amount of sweat losses and thermal stress during training. The table also needed to include an upper limit of hourly and daily fluid intake to restrict soldiers from vastly overdrinking when the mission required deviation from the recommended guidance. This was accomplished by adding upper limits for hourly and daily water intake.

We initially predicted the work:rest ratio which would support work in the hot weather using a computer simulation program that predicts core temperature and sweating responses of soldiers during work. We then validated the predictions by having soldiers walk at intensities which produced the metabolic rates accompanying low, moderate and hard military tasks in climatic conditions eliciting Heat Category I, III and V conditions. These three hot weather conditions were chosen to evaluate the full range of heat categories within the table. We chose to focus on warm-humid conditions since these are the prevailing climatic conditions for most U.S. Army Basic Training posts.

An important finding from our laboratory experiments was that the computer simulations modestly overpredicted the sweating responses. The sweating rates for men ranged from 0.03 qt/h to 0.33 qt/h lower than the predicted values. The experiments produced several instances where the difference between the observed and predicted equaled or exceeded $\frac{1}{4}$ qt/h. In these instances, the recommended volumes for the specific heat category-exercise intensity combination were modified to reflect the responses of the men. In situations where the measured sweating rate averaged between the predicted and $\frac{1}{4}$ qt/h less than predicted, the range of responses were examined and an arbitrary judgement made between potentially underestimating sweat loss or overestimating sweat loss by a small amount. In all cases, the recommended fluid intake was set to fully replace the expected sweat loss.

Examination of the rectal temperature responses to the 2 h exercise-heat stress revealed that the predicted work times were approximately correct - as during most exercise conditions, rectal temperatures remained below 38.5°C during the 2 h observation period and extrapolation to 4 h did not suggest that core temperatures would exceed 38.5°C over this longer time period. These data suggest that the work:rest recommendations are appropriately conservative to limit the number of soldiers expected to become heat casualties from working too long and/or too hard in hot weather. In the three instances (low intensity - Heat Category V, moderate intensity - Heat Category V, and high intensity - Heat Category V) where the predicted work:rest times did not prevent core temperature from progressively rising during work, work:rest times were modified to reduce the amount of work performed each hour.

The original predictions for fluid intake were much greater than the observed sweating rates for the female volunteers. This was expected, however, as it is well recognized that females generally sweat less profusely than men and the models were derived using data from male volunteers. While the modifications to the fluid intake portion of the guidelines does correct for some of the differences between the observed female sweating rate and the predicted sweating rates, a phrase was added to the table legend which states that actual fluid replacement needs may deviate from the recommended amount by +/- ¼ qt/h.

The proposed fluid replacement guidelines are presented in table format and designed to provide the user with easy to locate recommendations for work:rest time and fluid intake during warm weather operations. The user locates the existing weather condition on the left column and then reads the recommended work:rest time and fluid intake for the planned physical activity. The table includes reference tasks for each work intensity to help the user determine whether their task is either an 'easy', 'moderate' or 'hard' soldier task. The guidelines inform the user that the recommendations are set to support 4 h of work. It also specifies an upper limit to hourly and daily water intake to put in an additional safeguard against excessive overdrinking and development of water intoxication.

A weakness of the guidelines are that it only provides guidance for sustained work in a specified heat category. In many scenarios, only 1-2 h of moderate or hard

work will be planned interspersed with several hours of easy work. In this scenario, the recommended work times for moderate and hard work periods are overly conservative. However, the information in the table is sufficiently robust that the soldier community should be able to modify the table for their needs and still sustain appropriate hydration. For example, if soldiers deviate from the recommended work time and attempt to extrapolate the appropriate hourly fluid intake, the legend cautions the user not to drink in excess of 1.5 qt/h and no more than 12 qt/day. In the event that the soldier increases their work time per hour but doesn't modify their fluid intake, the original recommendations will still prevent excessive dehydration during several hours of activity.

In summary, this technical report summarizes the development and validation of fluid replacement guidelines during warm weather training. The end product is an easy to read table that provides the user with the appropriate work:rest time and fluid intake to support work during warm weather training. It includes the range of warm weather conditions likely to be encountered during training/military operations and covers the a broad range of military activities. It is expected that the table will sustain hydration and reduce the number of heat injuries during military training while protecting the soldier from becoming sick from overdrinking during training.

REFERENCES

Hyponatremia associated with heat stress and excessive water consumption: Outbreak Investigation and recommendations. Medical Surveillance Monthly Report (MSMR) 3:9-10, 1997.

Kraning, KK, Gonzalez RR. A mechanistic computer simulation of human work in heat that accounts for physical and physiological effects of clothing, aerobic fitness, and progressive dehydration. J Therm Biol 22: 331-342, 1997.

Medical Services Prevention of Heat Injury. U.S. Army Infantry Center, Fort Benning , Georgia, USAIC Regulation No. 40-14, May 29, 1990.

Pandolf, KB, Stroschein LA, Drolet LL, Gonzalez RR, and Sawka MN. Prediction modeling of physiological responses and human performance in the heat. Comput Biol Med 16:319-329, 1986.

Sawka MN, Wenger CB, and Pandolf, KB. Thermoregulatory responses to acute exercise-heat stress and heat acclimation. In: Handbook of Physiology: Environmental Physiology, edited by M. J. Fregly and C. M. Blatteis. New York: Oxford University Press, 1996, p. 157-185.

Sawka MN, Young AJ, Latzka WA, Neufer PD, Quigley MD, and Pandolf KB. Human tolerance to heat strain during exercise: influence of hydration. J Appl Physiol 73: 368-375, 1992.

APPENDIX A. FORT BENNING EPICON FINAL REPORT

MCHB-DC-EDE

29 August 1997

MEMORANDUM FOR CDR, MARTIN ARMY HOSPITAL, FT BENNING GA

SUBJECT: EPICON: Overhydration with Secondary Hyponatremia at Ft. Benning, GA Final Report

1. Executive Summary.

a. In late July 1997, Martin Army Community Hospital (MACH) notified the US Army Center for Health Promotion and Preventive Medicine (USACHPPM) that 5 cases, one terminating fatally, of apparent hyponatremia in trainees had been identified during the month. An epidemiological consultation (EPICON) was requested to assist in the investigation of these cases.

b. MAJ William Corr, Preventive Medicine Officer, Ft Benning, recommended immediate water policy changes to reduce the number of cases, and developed and initiated a study protocol to assess the prevalence and risk factors associated with exertional hyponatremia and fluid consumption in basic trainees. The USACHPPM, US Army Research Institute of Environmental Medicine (USARIEM), and Nephrology Department, Madigan Army Medical Center initially facilitated MAJ Corr's efforts with epidemiologic, physiologic, and clinical expertise.

c. An EPICON was conducted 27-29 August to further assist MAJ Corr's investigation, refine the problem definition, and provide recommendations for continued research and, potentially, water policy changes.

2. Historical.

a. The ICD-9 code for "hyposmolality and/or hyponatremia" is 276.1. For surveillance purposes a case was defined as: 1) an only and/or primary diagnosis of 276.1, 2) any diagnosis of 276.1 plus any heat associated diagnosis (ICD-9 code 992.x), or 3) any diagnosis 276.1 plus any

MCHB-DC-EDE

SUBJECT: Overhydration with Secondary Hyponatremia at Ft. Benning

diagnosis of "fluid overload" (ICD-9 code 276.6)

b. The IPDS (1989-1996) provided 125 hospitalizations which met one or more of the above criteria. The average number of cases per year was 15.6 (range 10-26). Males accounted for 84.8% of cases. The majority of cases occurred from June through August. Forty percent of the cases occurred at Ft Benning.

3. Findings.

a. All 11 hyponatremia cases at Ft Benning for 1996-1997 were reviewed. These cases were characterized by being white, male, occurring early in the training cycle, having a large oral water intake, mental status changes, nausea, and vomiting. All occurred in a setting of heat stress and moderate to heavy activity.

b. Only 2 of the cases demonstrated an elevated rectal temperature, and both of these cases had primary diagnoses of infectious etiology.

c. The average serum sodium was 121 mOsm (range 116-133). Serum and urine osmolality data was incomplete on 10 of the cases.

d. The training cadre at Ft Benning have been aggressive and thorough in implementing army water replacement doctrine. Unfortunately, this doctrine, for heat category 5 conditions, is inappropriate as it outstrips the body's ability to process such a large volume of water and maintain electrolyte balance.

e. A revised heat injury prevention and treatment policy which increases early detection and monitoring of heat injury cases, and the volume of water these soldiers consume over time, has been implemented on post.

4. Conclusions.

a. Eleven cases of hyponatremia in a setting of heat stress and heavy activity in previously

MCHB-DC-EDE

SUBJECT: Overhydration with Secondary Hyponatremia at Ft. Benning

healthy individuals have occurred at Ft Benning during 1996-97.

- b. All cases have been associated with a large oral water intake.
- c. The training cadre on post are to be applauded for their diligent efforts to reduce heat injuries among trainees.
- d. The current army doctrine for maximal fluid replacement per hour needs revision.
- e. The revised local heat injury prevention and treatment policy is appropriate.
- f. MAJ Corr's investigation is proceeding as planned.

5. Recommendations.

- a. The Preventive Medicine Service, MACH and the USACHPPM should develop a questionnaire for use by the Emergency Medicine Department to capture demographic and risk factor data on each case. (Case definition: a soldier with a serum sodium $<130\text{mOsm}$ in a setting of heat stress or heavy activity in a previously healthy individual).
- b. Fluid replacement requirement doctrine for the army needs to be reviewed and corrected by USARIEM and the Nephrology Department, MAMC.
- c. Once new fluid replacement doctrine is established, the USARIEM should conduct study protocols to validate the doctrine.
- d. Continuing research efforts should include the elucidation of environmental, demographic, and physiologic factors which bear on the development of hyperhydration and hyponatremia in military trainees in a hot climate.
- e. The USACHPPM, USARIEM, and Nephrology Department, MAMC should continue to assist MAJ Corr in his investigation.

MCHB-DC-EDE

SUBJECT: Overhydration with Secondary Hyponatremia at Ft. Benning

6. Point of contact for this message is the undersigned at (410)671-1054; DSN 584-1054.

STEPHEN C. CRAIG

LTC, MC

EPICON Team Chief

EPICON Team:

COL Howard Cushner

Dr. John Brundage

Dr. Michael Sawka

Dr. Joseph Knapik

CPT Scott Montain

**APPENDIX B. WATER AND WORK\REST CYCLE POLICY USED AT
FORT BENNING (FROM FM21-10, NOVEMBER 1988)**

CRITERIA		PMM	
HEAT CONDITION/ CATEGORY	WBGT INDEX (°F)	WATER INTAKE QUARTS/HOUR	WORK/REST CYCLE-MINUTES
1	78° - 81.9°	At least ½	Continuous
2	82° - 84.9°	At least ½	50/10
3	85° - 87.9°	At least 1	45/15
4	88° - 89.9°	At least 1 ½	30/30
5	90° - above	More than 2	20/40

**APPENDIX C. PRELIMINARY FLUID REPLACEMENT GUIDELINES
PROVIDED TO MARTIN ARMY HOSPITAL, FALL 1997**

MCMR-UE-TMD (70)

29 September 1997

MEMORANDUM FOR Commander, Martin Army Hospital, Fort Benning, GA
31905

SUBJECT: Fluid Replacement Guidelines for Training in Hot Weather

1. Reference Epidemiology Consultation at Fort Benning, GA 28-29 August 97 to investigate the incidences of clinical hyponatremia consequent to basic training activities.

2. At the request of the EPICON team and the Commander, Martin Army Hospital at Ft. Benning, GA, USARIEM has revised the water replacement guidelines for hot weather training. The changes proposed should minimize the likelihood of problems either from dehydration or water intoxication. The revised table is enclosed.

3. The procedures performed to generate the table are summarized below:

a. Estimated sweating rates were calculated using the USARIEM Heat Strain Model. Input variables and assumptions were: average size soldier performing easy (250 Watts, 3.5 kcal/min), moderate (425 Watts, 6 kcal/min) and hard (600 Watts, 8.6 kcal/min) military physical activities under ambient temperatures ranging from 70 to 110°F and 20 to 100% relative humidity during both full sun and full shade conditions. Wind speed for all calculations was kept constant at 2.5 mph. The uniform was the BDU, Hot weather.

b. The matrix was then collapsed by placing each weather condition in the appropriate WBGT index and averaging the sweating responses (T_{globe} was estimated by adding +27°F to ambient

MCMR-UE-TMD

SUBJECT: Fluid Replacement Guidelines for Training in Hot Weather
temperature for full sun and +0°F for shade conditions).

c. The fluid replacement table was then compared to another model (SCENARIO) which estimates sweating rates during exercise in hot weather conditions. The results of the second model generally verified the outputs of the USARIEM Heat Strain Model. However, in some cases the estimated sweating rates and temperature responses were less than the USARIEM Heat Strain Model. The work:rest ratios and water intake were revised to accommodate the differences between estimates.

d. The recommended rates of water intake and work:rest ratios were then validated, where possible, with existing data for soldiers wearing the BDU, Hot weather under varied climatic conditions.

e. Future plans include validating the sweating rates under simulated laboratory conditions and comparing the revised water doctrine to existing doctrine during U.S. Army Basic Training.

4. POC for this doctrine is CPT Scott Mountain (DSN 256-4564/
Comm 505-233-4564).

Encl

JOEL T. HIATT
Colonel, MS
Commanding

Fluid Replacement Guidelines* for Warm Weather Training (Average Acclimated Soldier wearing BDU, Hot Weather).

Heat Category	WBGT Index, °F	Easy Work		Moderate Work		Hard Work	
		Work /Rest	Water Intake, Qt/h	Work /Rest	Water Intake, Qt/h	Work /Rest	Water Intake, Qt/h
1	78-81.9	NL	½	NL	¾	40/20 min	1
2	82-84.9	NL	¾	NL	1	30/30 min	1
3	85-87.9	NL	1	40/20 min	1	30/30 min	1¼
4	88-89.9	NL	1	30/30 min	1¼	20/40 min	1¼
5	> 90	NL	1¼	30/30 min	1¼	15/45 min	1¼

* Volumes listed are required to support work/rest times listed for each work level. NL, no limit to work time per hour. Hourly fluid intake should not exceed 1½ quarts. Daily fluid intake should not exceed 10 quarts.

NOTE: MOPP gear or body armor adds 10°F to WBGT Index. Rest means minimal physical activity (sitting or standing) and should be accomplished in shade if possible.

Easy Work	Moderate Work	Hard Work
<ul style="list-style-type: none"> • Weapon Maintenance • Walking Hard Surface at 2.5 mph, ≤ 30 lb Load • Manual of Arms • Marksmanship Training • Drill and Ceremony 	<ul style="list-style-type: none"> • Walking Loose Sand at 2.5 mph, No Load • Walking Hard Surface at 3.5 mph, ≤ 40 lb Load • Calisthenics • Patrolling • Individual Movement Tech. i.e. low crawl, high crawl • Defensive Position Const. • Field Assaults 	<ul style="list-style-type: none"> • Walking Hard Surface at 3.5 mph, ≥ 40 lb Load • Walking Loose Sand at 2.5 mph with Load